A Stochastic Framework for Analyzing Long-run CO2 Abatement Strategies

A Project of the
California Energy Modeling and Analysis Consortium (CEMAC)

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About CEMAC

- Initiated in 2005 by Jane Long, Associate Director, Energy & Environment Directorate, Lawrence Livermore National Laboratory – funding provided by LLNL

- Research team:
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  - Alex Farrell, UC Berkeley
  - P. S. Koutsourelakis, Cornell
  - Alan H. Sanstad, LBNL
  - Sonia Yeh, LLNL

- Goal is to develop advanced quantitative methods for addressing energy and environmental policy issues

Policy and methodological context

- Policy problems are increasingly complex and inter-connected, and must be approached comprehensively -
    - GHG emissions reductions and carbon management
    - Petroleum supply security and import dependence
    - Large-scale transition to a sustainable energy system
- Analytical methods must jointly address a host of factors, including
    - Uncertainty
    - Technological innovation
    - Outcomes of R&D
    - Demand response to prices
    - Public policies (e.g. markets vs. command and control)
    - Social and political influences and dynamics

Addressing Long-run Energy-Environmental Issues

- Numerical models are the dominant tool, including
  - Computable general equilibrium (CGE)
  - Partial equilibrium energy system
  - Optimization, mathematical programming
- Key trends in model development have been toward
  - Increasing levels of detail and complexity
  - Longer time horizons for application to climate and GHG policy
- The resulting dilemma: Both the detail and the time horizons are needed for policy-making, but
  - "Black-box" problem: Models, and their outputs, may be very difficult to understand
  - Significant but mostly un-analyzed uncertainties in policy prescriptions, underlying data, model structures and assumptions, etc.
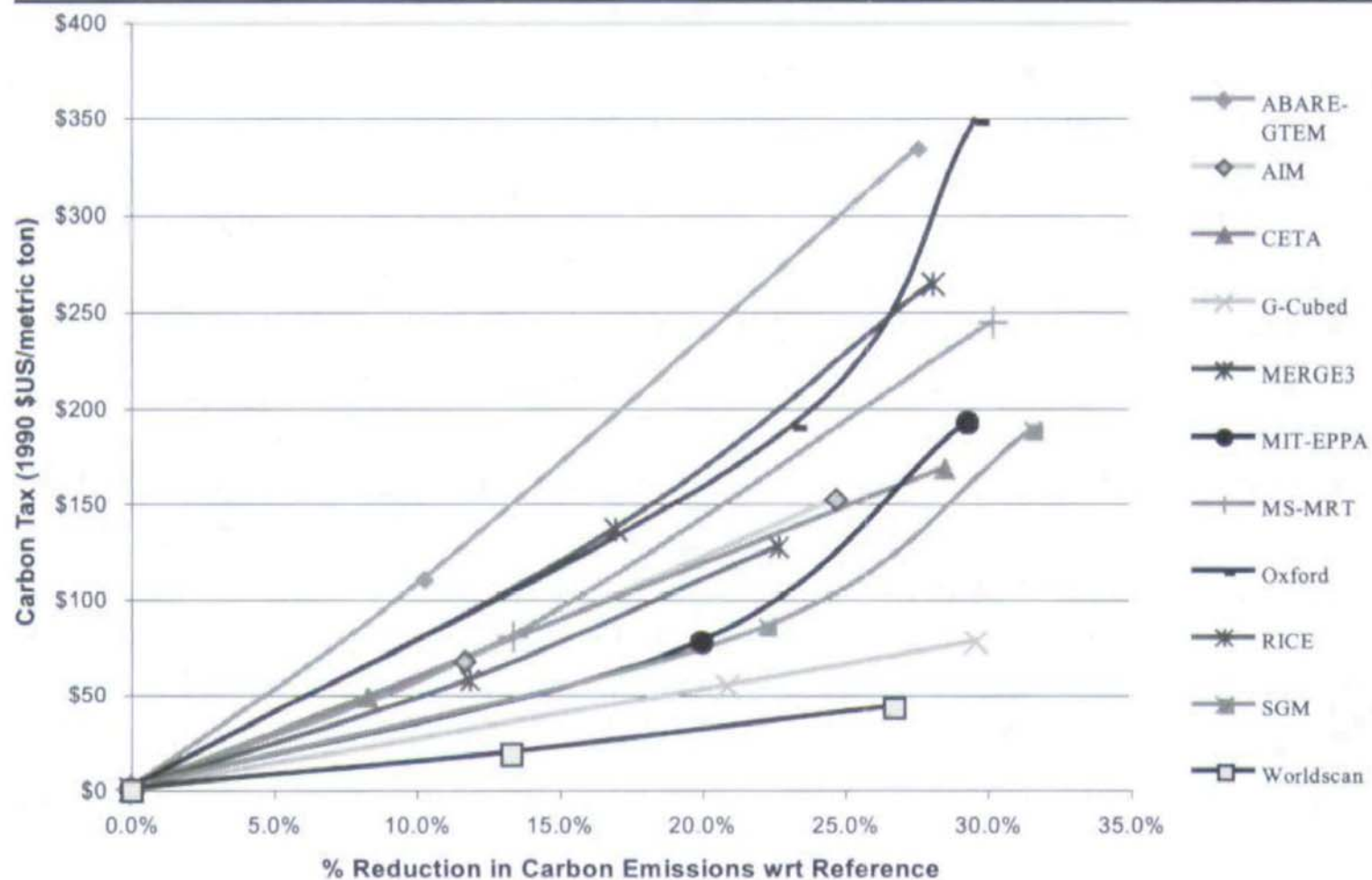
Figure 1. EMF-16 Model Predictions of Marginal Abatement Costs for the US Derived from the No Trade and Annex I Trading Scenarios[10]

Table TS.3. Carbon Prices at Various Points in Time for the Stabilization Scenarios

Stabilization Level	2020 ($/tonne C)			2030 ($/tonne C)		
	IGSM	MERGE	MiniCAM	IGSM	MERGE	MiniCAM
Level 4	$18	$1	$1	$26	$2	$2
Level 3	$30	$2	$4	$44	$4	$7
Level 2	$75	$8	$15	$112	$13	$26
Level 1	$259	$110	$93	$384	$191	$170

| Stabilization Level	2050 ($/tonne C)			2100 ($/tonne C)		
	IGSM	MERGE	MiniCAM	IGSM	MERGE	MiniCAM
Level 4	$58	$6	$5	$415	$67	$54
Level 3	$97	$11	$19	$686	$127	$221
Level 2	$245	$36	$69	$1,743	$466	$420
Level 1	$842	$574	$466	$6,053	$609	$635

These assumptions of where, when, and *what*   See Box 3.2 for more on converting between

Addressing uncertainties using existing models

- Our current focus is analyzing strategies, pathways, policies, etc., for achieving significant long-run CO_2 emissions abatement at "reasonable" cost, e.g.,
  - AB32 2050 target
  - Bingaman, McCain-Lieberman, and other bills in the U. S. Congress
- The technical challenge is to
  - Address major uncertainties while
  - "Leveraging" existing models that are being used to study this problem but are not designed for uncertainty analysis
  - Do this in a way that increases *insight* rather than *complexity*

NEMS Projection: Primary Energy Consumption by Fuel (quadrillion Btu)
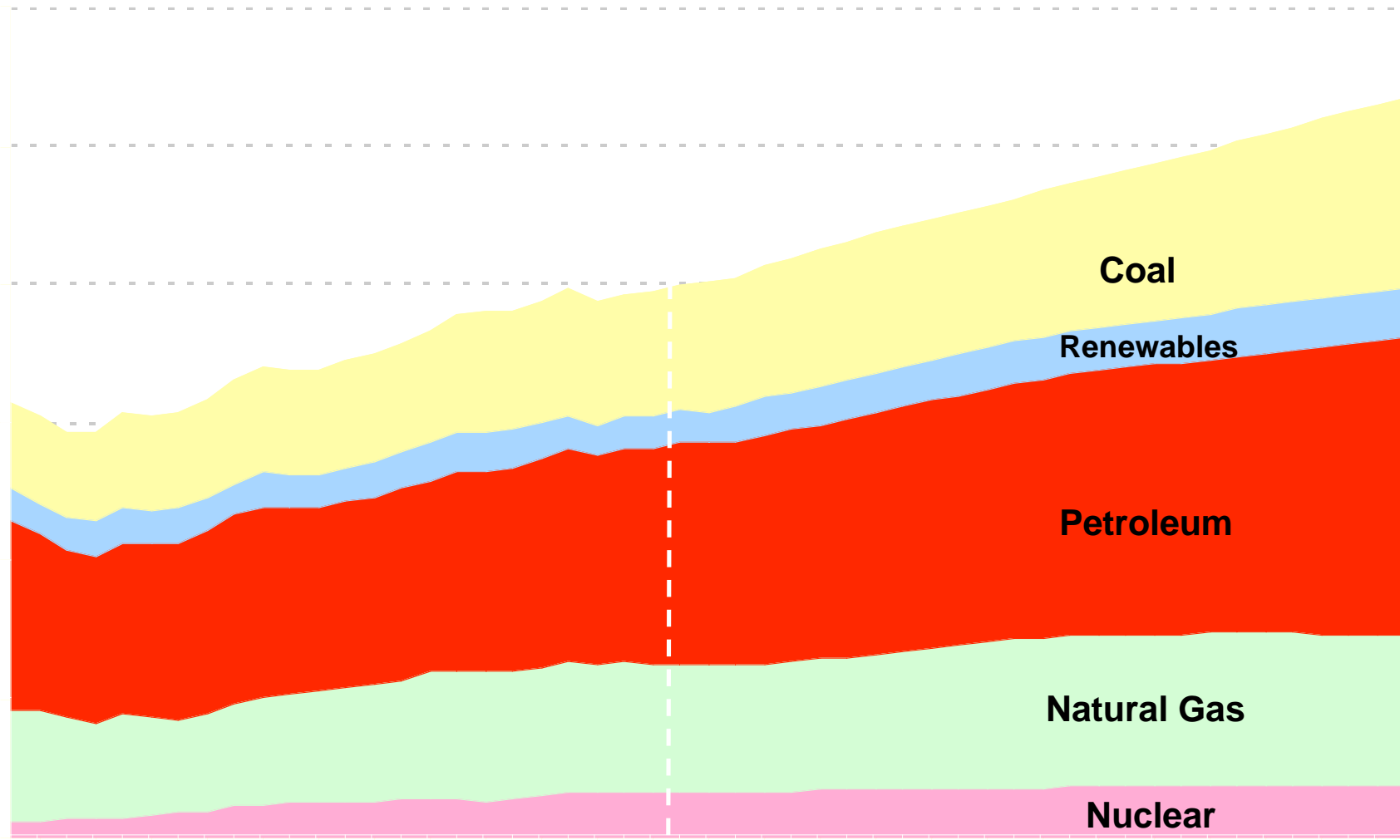
MARKAL model output variation using Monte Carlo
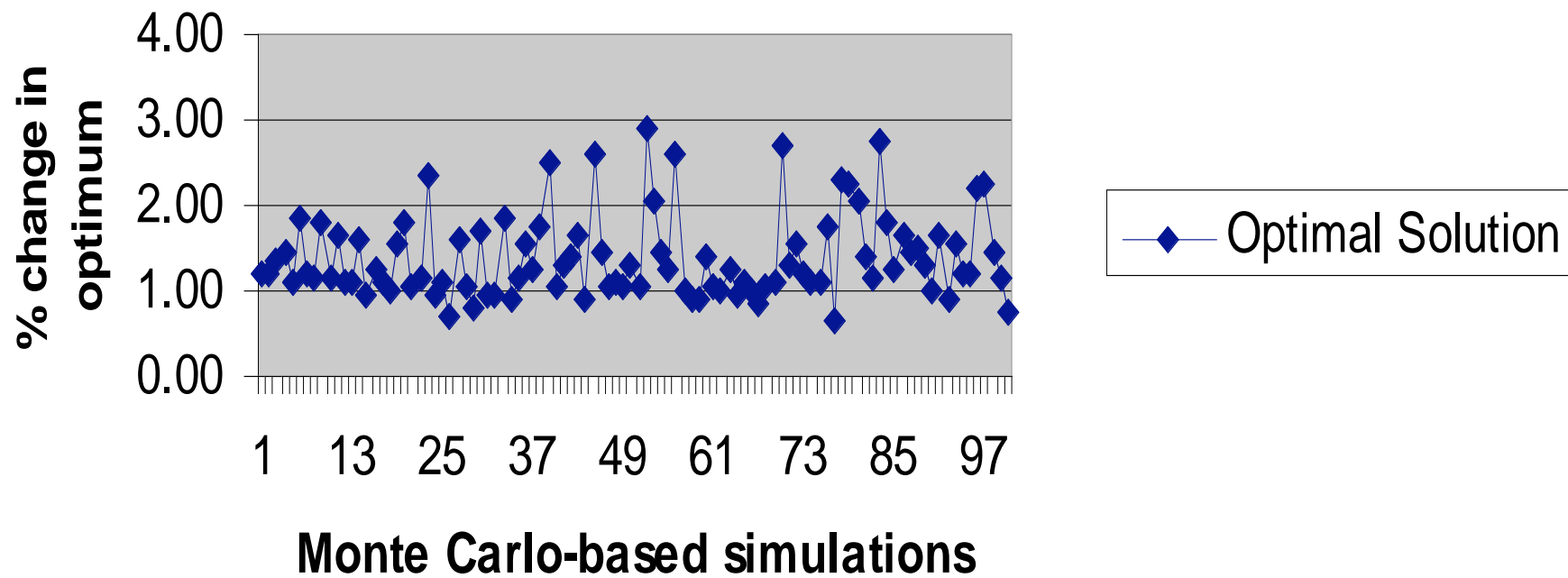
From a forecasting-based to a goal-directed framework

- We approach modeling and analysis of long-run cost effective abatement as a *system design* problem under conditions of

  - Uncertainty about future values of key parameters
  - Complexity of both the underlying policy problem and the model(s) we use to analyze it

- We also take into account that the ultimate "appropriate" emissions reductions targets are uncertain (although the political process deals with specific values)
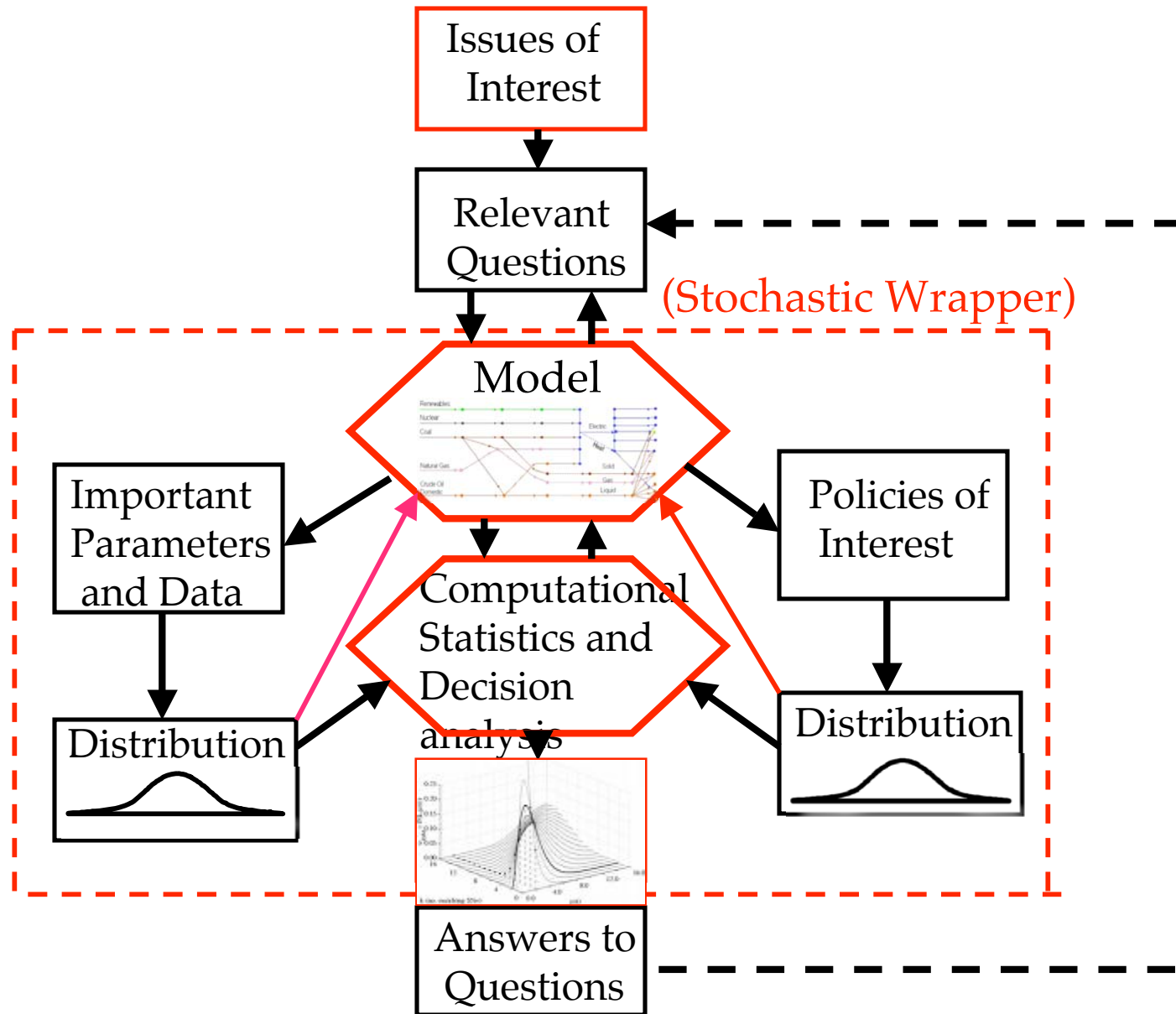
Defining the problem

- Given
  - Probabilistic uncertainties in key model parameters
  - Model variables and/or parameters that represent social, policy, and political decisions determining the implementation of emissions abatement strategies

we characterize the "policy landscape" and identify regions likely to meet policy goals

- Our current example: Given
  - Uncertainties in characteristics – such as costs – of future low-carbon technologies, and in fuel prices and
  - Low-carbon technology deployment rates as "policy levers,"

What policy choices are likely to succeed in reducing national energy-sector CO2 emissions by 30-50% by 2050 with no more than a 1% increase in GDP?

Technical approach

- This fits within the paradigm of certain problems in engineering reliability theory:
  - Choose design features of a complex system under uncertainty so as to maximize the probability of successful system performance

- The "complex system" is an existing computer model, to which we apply methods of computational statistics and decision analysis within a specially-designed software environment:
  - Sequential importance sampling
 - Statistical learning and Bayesian inference

Analytical and computational framework

Issues of Interest

Relevant Questions

(Stochastic Wrapper)

Model

Important Parameters and Data

Policies of Interest

Distribution

Computational Statistics and Decision analysis

Distribution

Answers to Questions

What "answers" look like

- This overall architecture is that of "inverse" methodologies: Given a target, goal, or other desired state, how do you get there?
- We can compute, for example:
  - Landscapes or regions that yield specified likelihoods of meeting the joint emissions/cost criterion
  - Regions that yield specified emissions reductions for a given likelihood
- We can explore *global* model sensitivities under uncertainties
- The following graphs illustrate these ideas when the policy levers are deployment levels of low-carbon technology deployment, and uncertain parameters are future technology costs and fuel prices

# Fixed Probability Surfaces for a Varying CO2 Reduction

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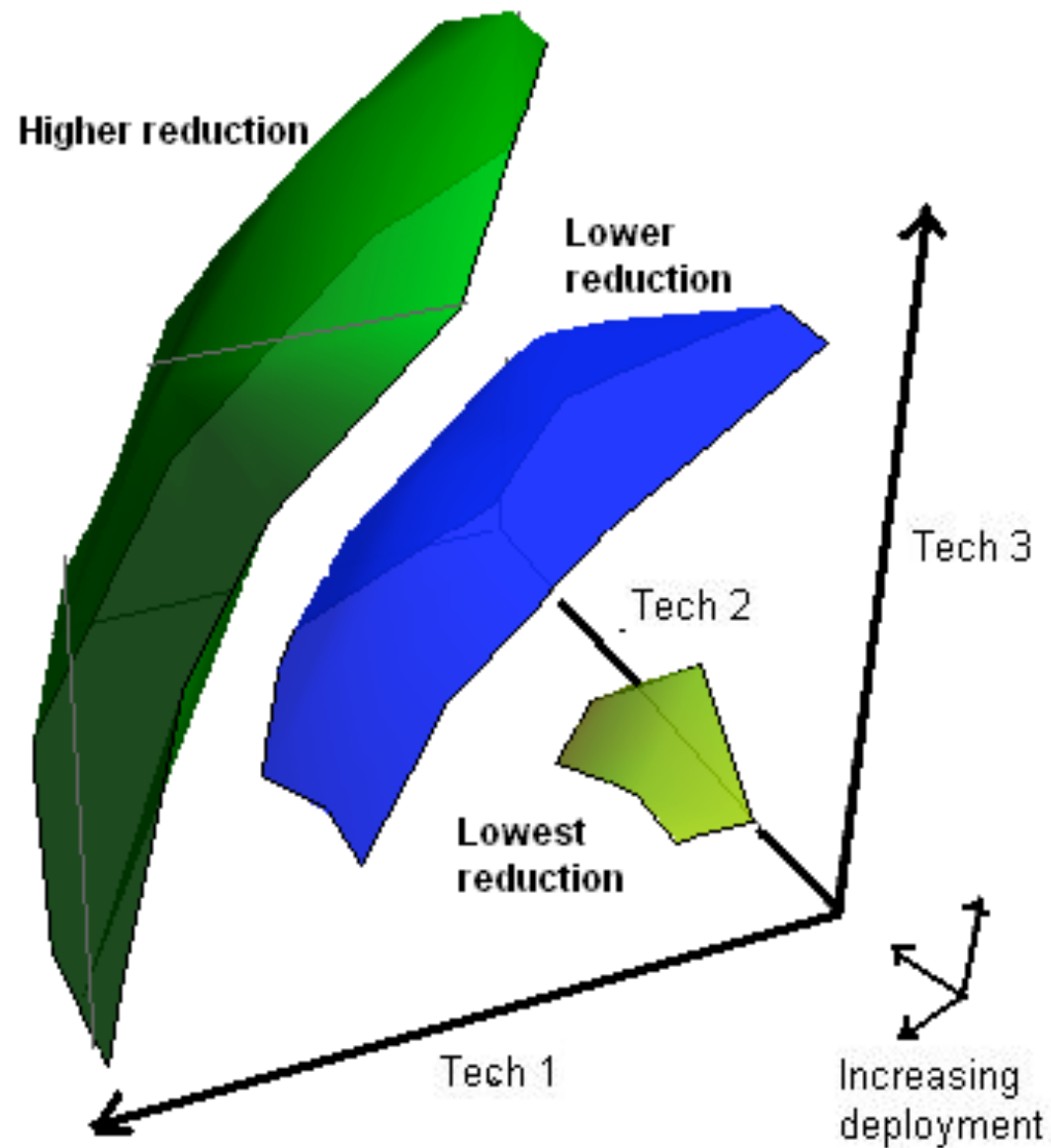
Varying Iso-Probability Surfaces for a Fixed CO2 reduction

16
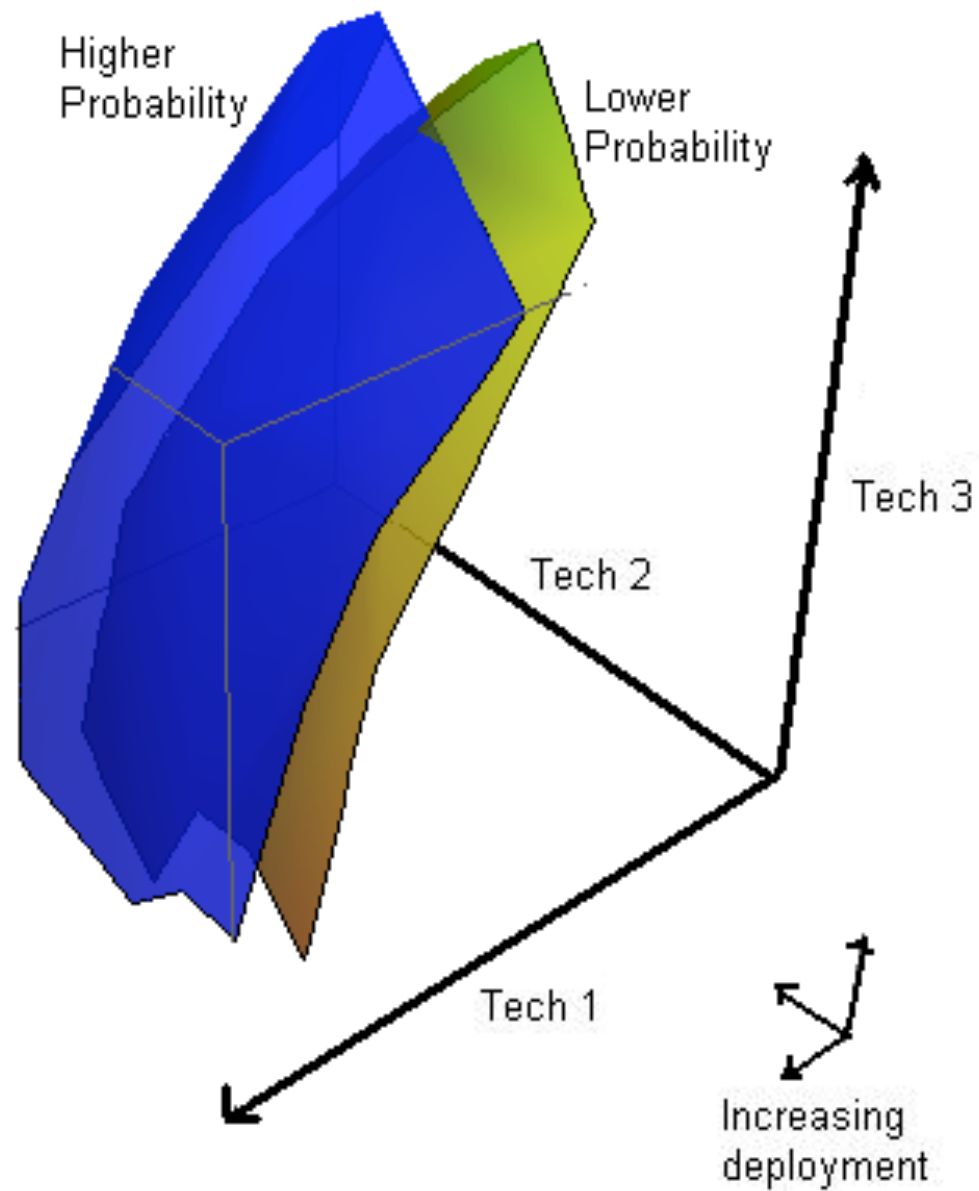
Current demonstration project

- "Kernel" model: MARKAL
  - *M*arket *A*llocation - General framework for an energy system planning model, originally developed at Brookhaven National Laboratory in the 1970s
  - Deterministic inter-temporal linear programming model, emphasizing technological detail
  - We are using the US EPA's version (database) – time horizon recently updated to 2050

Simplified MARKAL "Reference Energy System"
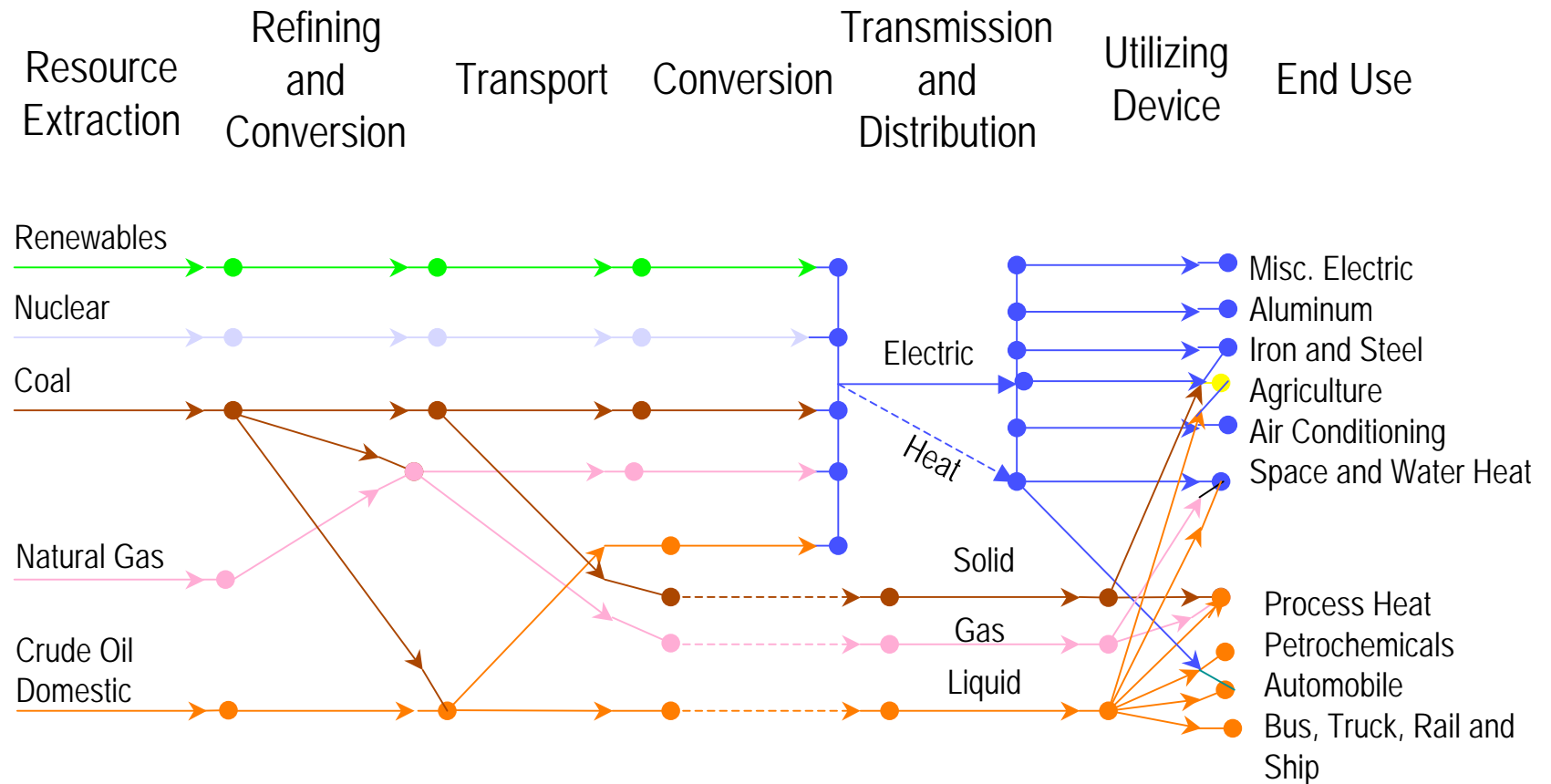
Objective: Minimize discounted Total Energy System costs
Decision variables: Fuel uses, technology investments, imports/exports
Constraints: Satisfy Energy Demands
         Use Only Available Resources
         Use Only Available Technologies (costs and efficiencies)

First experiments:
Electric power and transportation

- Policy questions:
  - How can increased deployment of
    - Low-carbon generation and efficient electricity end-use technologies, and
    - Biofuels

    contribute to meeting long-run cost-effective abatement goals?
  - How do interactions between the electricity and transportation sectors affect policy choices and outcomes?
- Uncertainties in technology costs, oil and natural gas prices, feedstock and conversion costs – and *correlations*
- Policy levers: Technology R&D, deployment decisions

Conclusion

- We have developed an analytical and computational methodology for analyzing complex, long-run energy/environmental policy problems that
  - Addresses fundamental uncertainties in forecasting, measurement, and model design
  - Applies modern tools of computational statistics, decision analysis, economics, and software engineering
  - Leverages existing numerical models, technology information, and other resources
  - Moves from a forecasting to a goal-oriented, system design paradigm
  - Enables identification of robust policy strategies
- Demonstration projects will be completed by December 2007 – planning and funding solicitations for future work are underway